V.Novikov,

V.Ivanov, K.Koshelev, V.Krivtsun, A.Grushin,

R.Kildiyarova, A.Solomyannaya

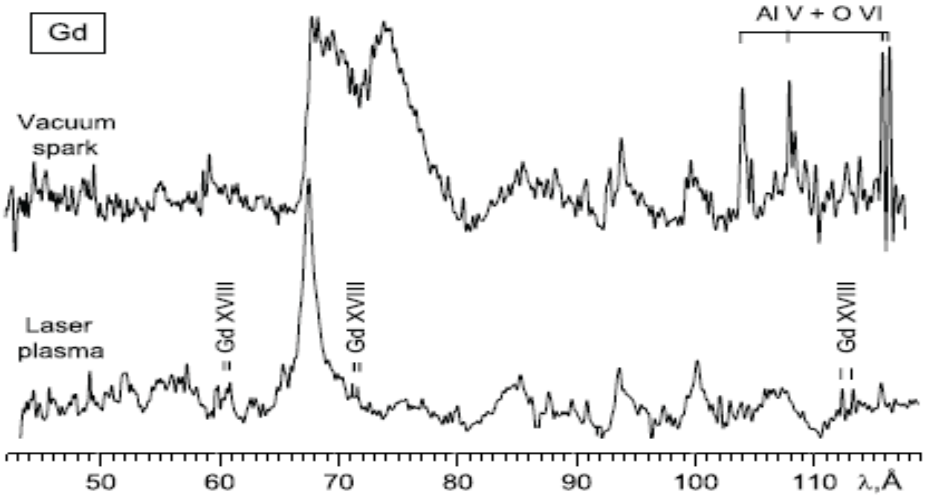
Peculiarities of Modeling LPP Source at 6.X nm

Outline

- Theoretical base
- Optimal plasma parameters
- Band position
- Scaling CE by RZLINE modeling
- Laser types: Nd YAG vs CO_2
- Conclusion

Fuel at λ~ 6.5-6.7 nm

Gd



S S Churilov, R R Kildiyarova, A N Ryabtsev and S V Sadovsky Phys. Scr. **80** (2009) 045303

Tb

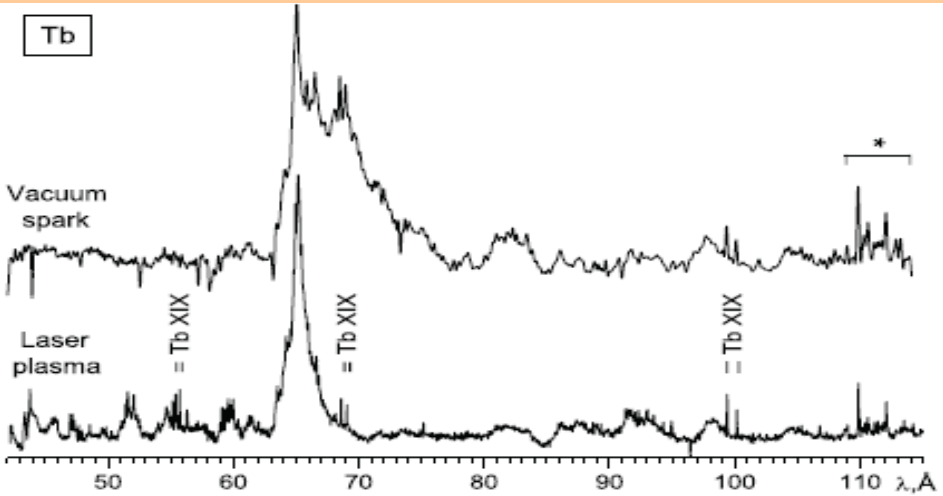


Figure 2. Spectra of terbium ions excited in the vacuum spark (upper trace) and in the laser-produced plasma (bottom trace). ∗, $4f^2$–$4f5d$ transition array in Tb XVIII classified in the present work.

THERMOS_BELINE code

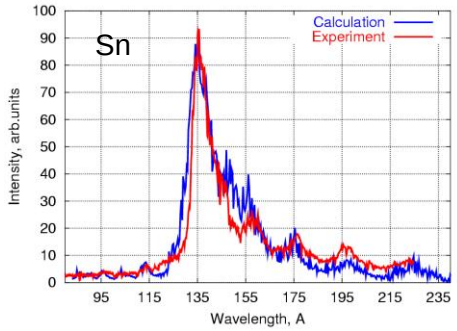
COMPUTING OF LEVEL KINETICS & RADIATION TRANSPORT

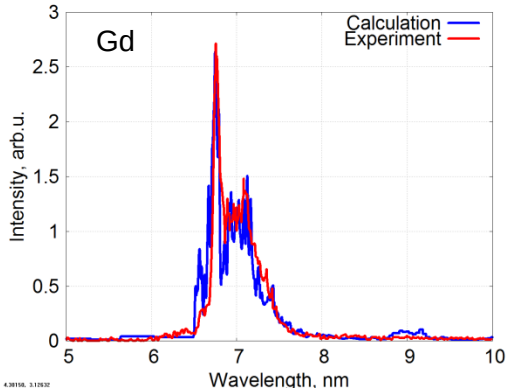
- **Main purpose:**

- **to get CRE tables with arbitrary radiation field;**
- **obtaining the realistic emission spectra;**
- **in-line version for radiative hydro-dynamics;**

Method:

- **special averaging with given photon energy grid;**
- **usage the stored data prepared beforehand.**





The code makes possible self-consistent calculation of level kinetics and radiation transport for arbitrary plasma configurations.

The code includes:

radiation transport of overlapped spectral lines with arbitrary optical thickness and realistic line profiles;

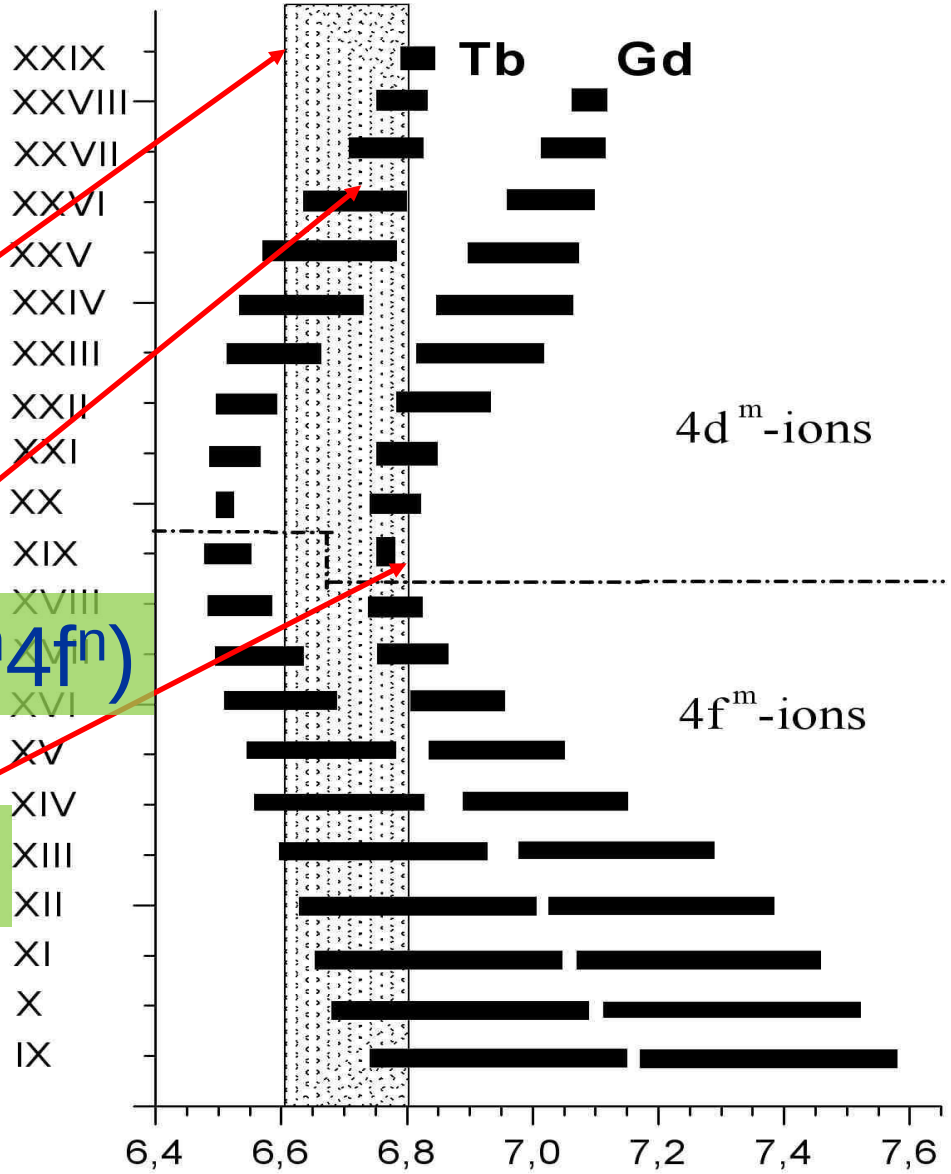
verified atomic database for low-Z materials (H, He, C, N,O) and also for Xe, Sn, W, Tb, Gd.

Gd & Tb ions emission

Mirror 6.6 - 6.8 nm

Tb XXIII - XXX ($4p^k4d^m4f^n$)

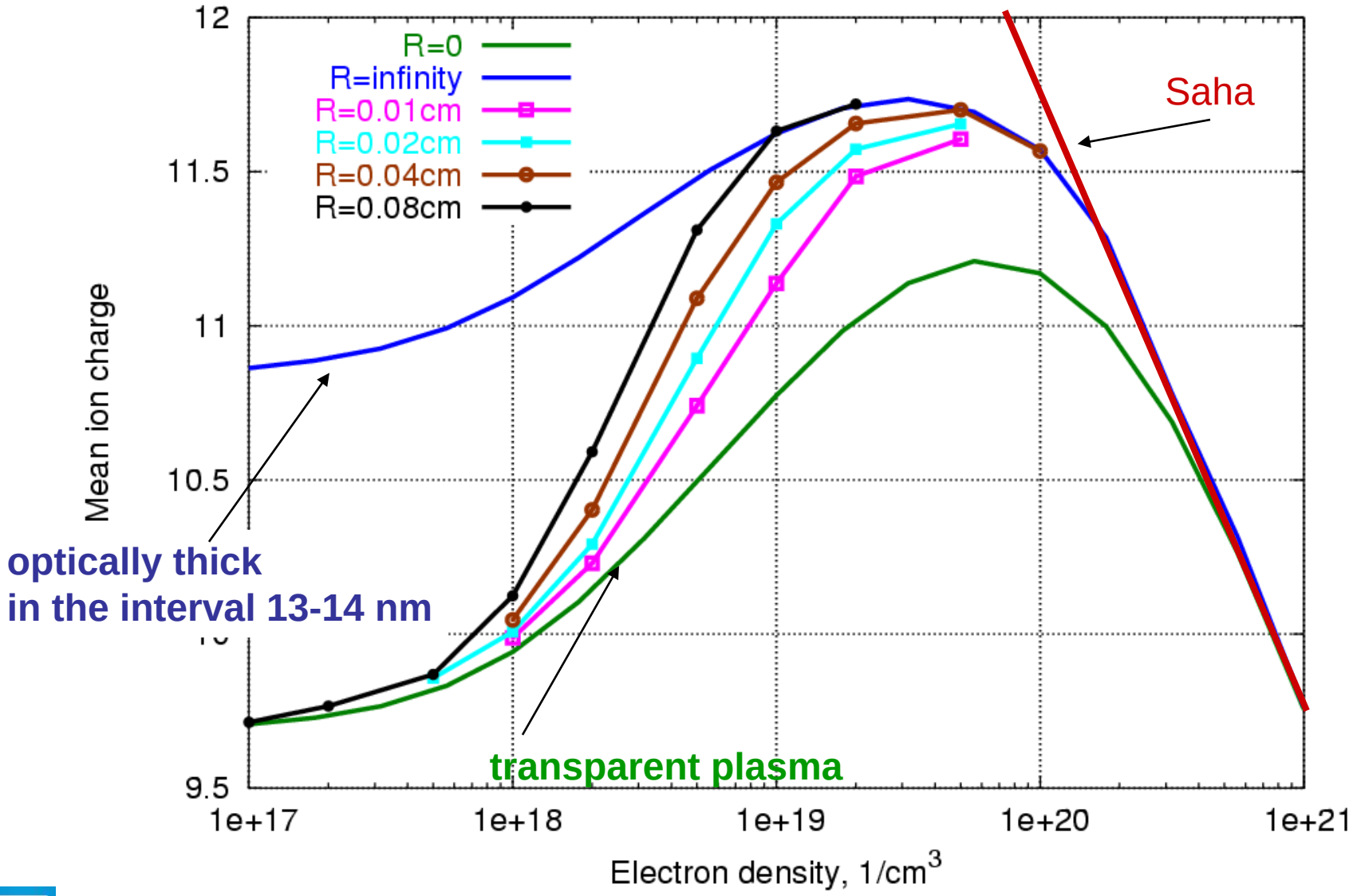
Gd XVII - XXII ($4d^m4f^n$)



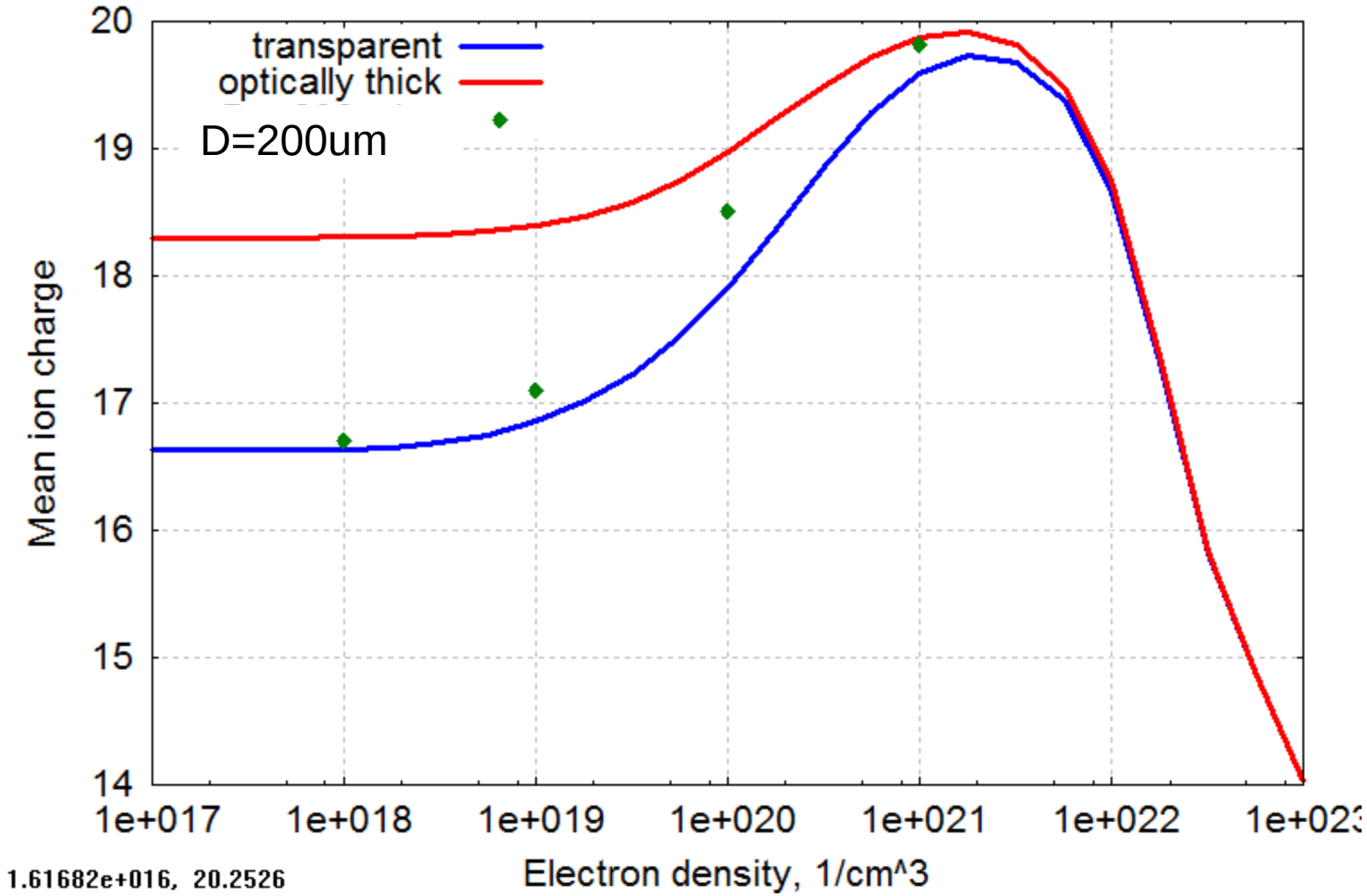
Sn (13.5) vs Gd (6.x)

Material	Sn	Gd
Band	2% at 13.5 nm	0.6% at 6.x
Ions	VIII - XIV	XVII - XXII
Temperature	~ 35 eV	~ 100 eV
Size	~ 200 um	~ 200 um
Optical thickness		
Electron density		
CE		

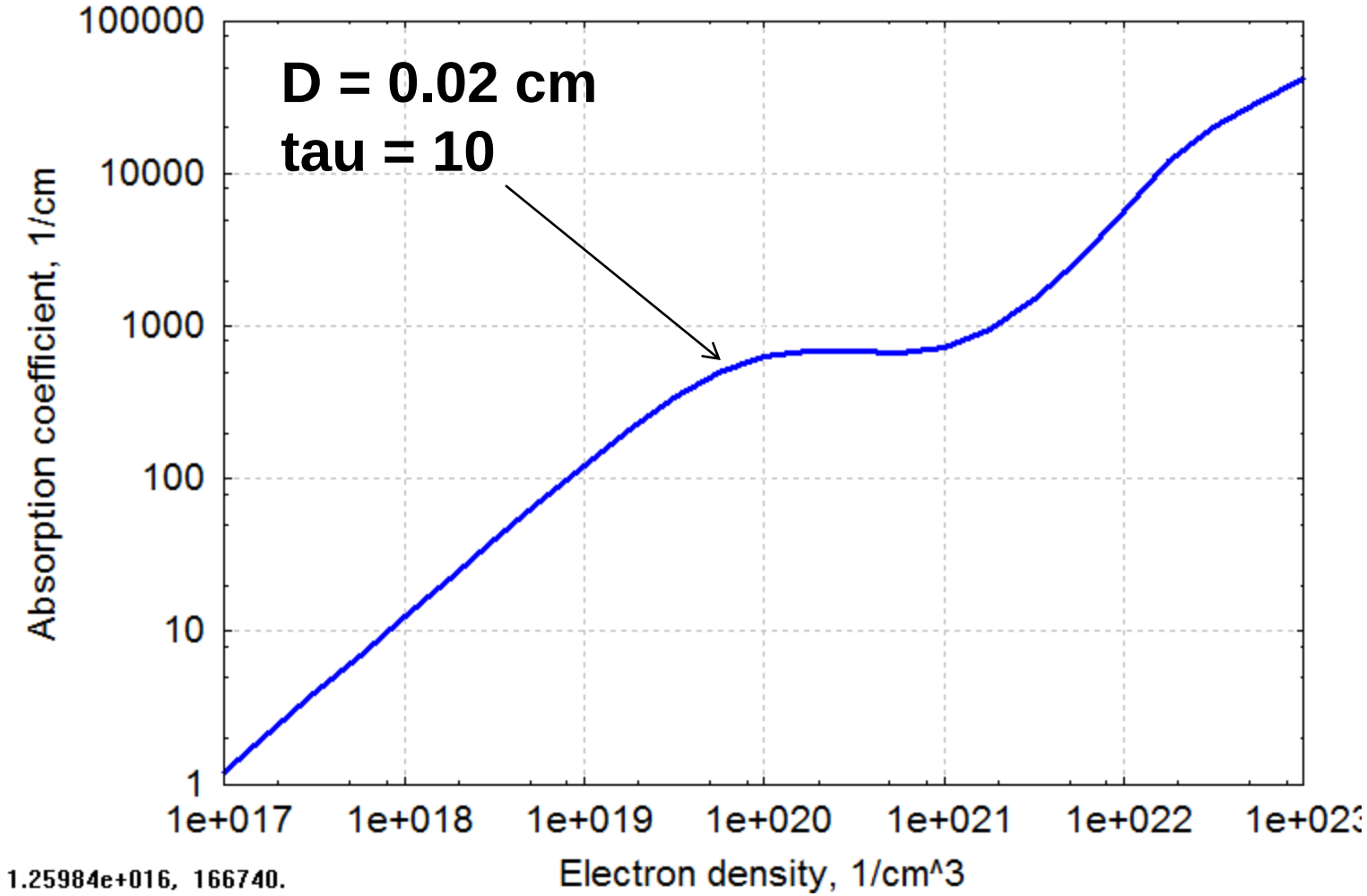
Sn ionization: T=32.5 eV



Gd ionization at T=90 eV



Gd absorption in band



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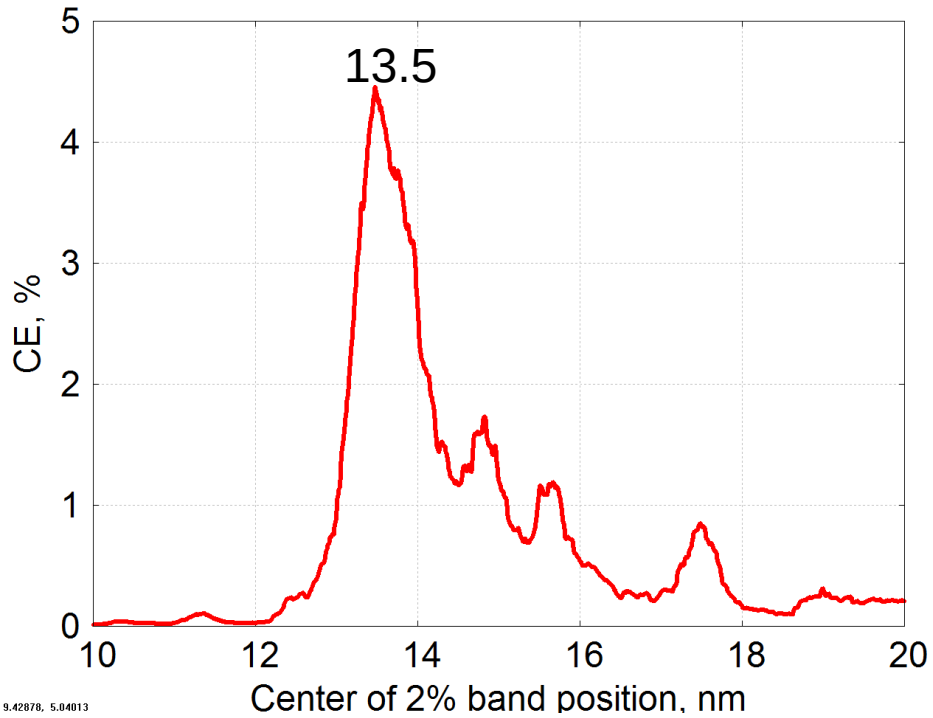
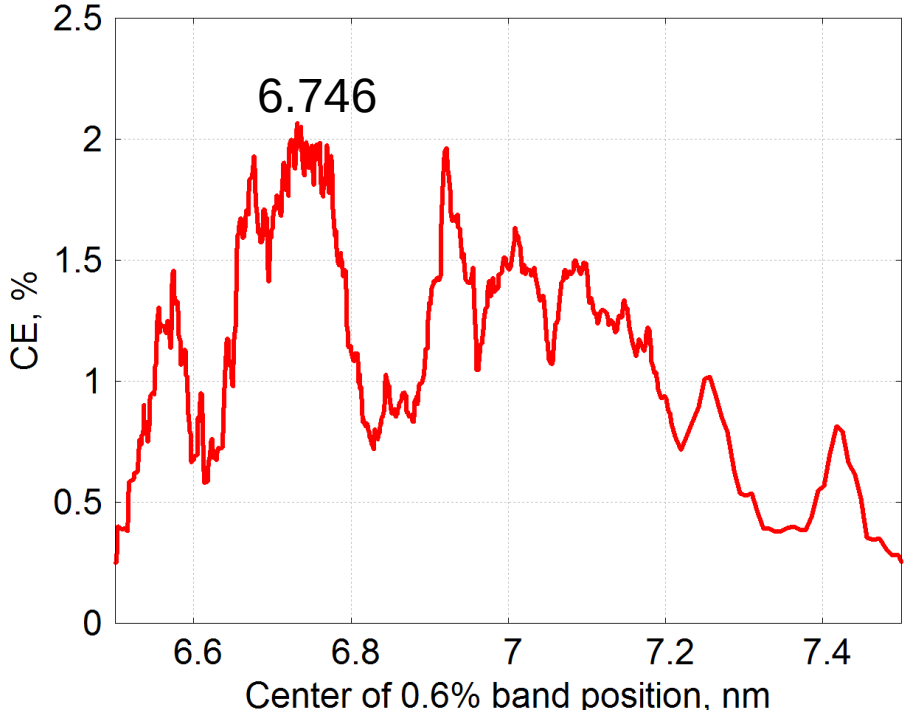
Temperature	~ 35 eV	~ 100 eV
Size	~ 200 um	~ 200 um
Optical thickness	~ 1	~ 1
Electron density	~ 10^{19} 1/cm^3	~ 10^{20} 1/cm^3
CE		

Position of band

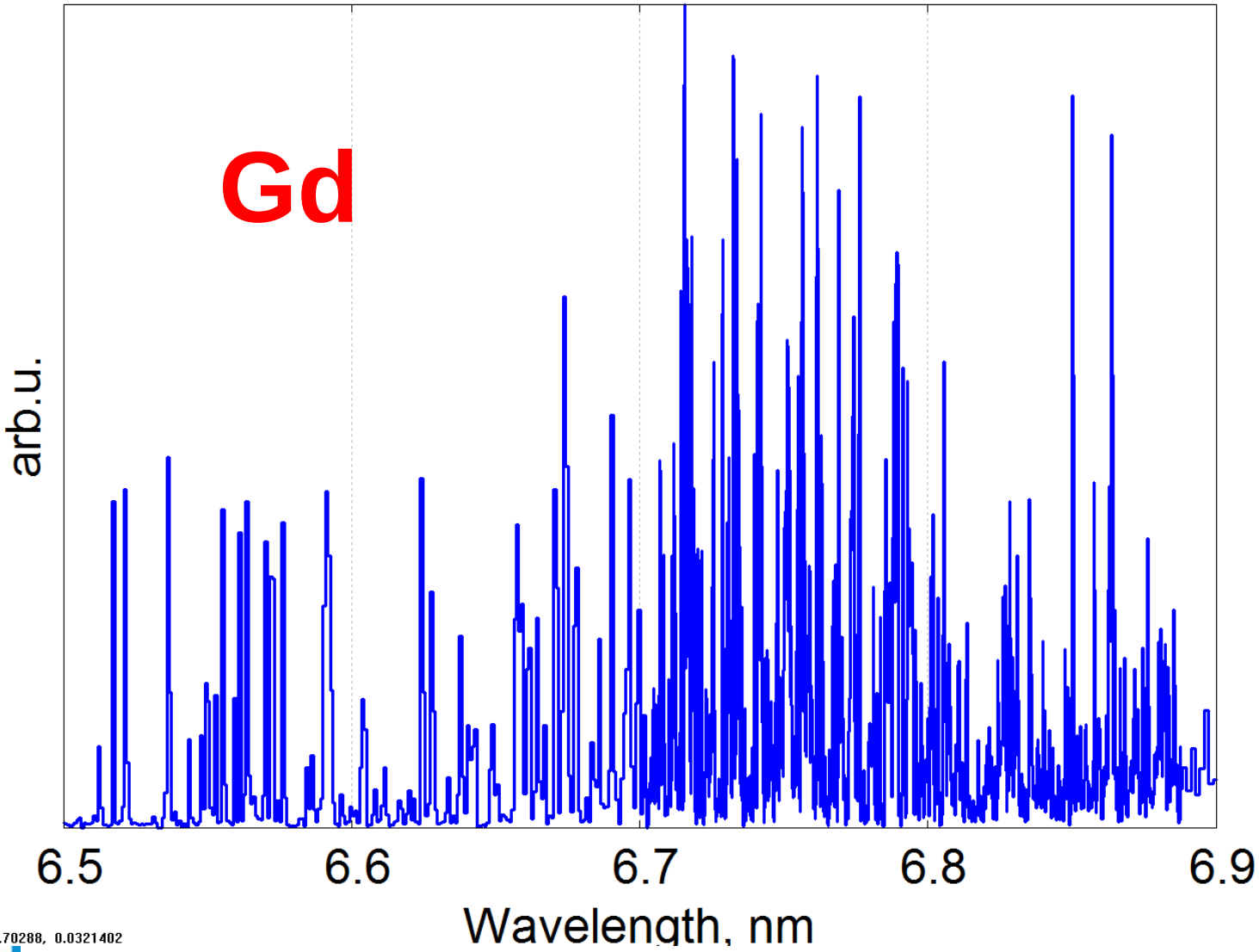
Sn



Gd

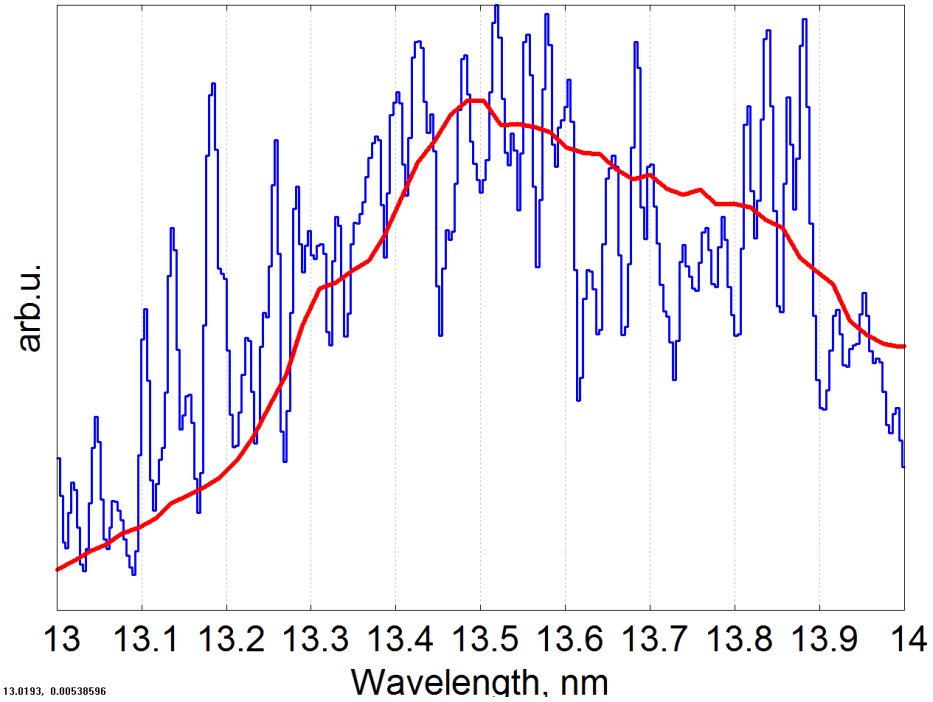


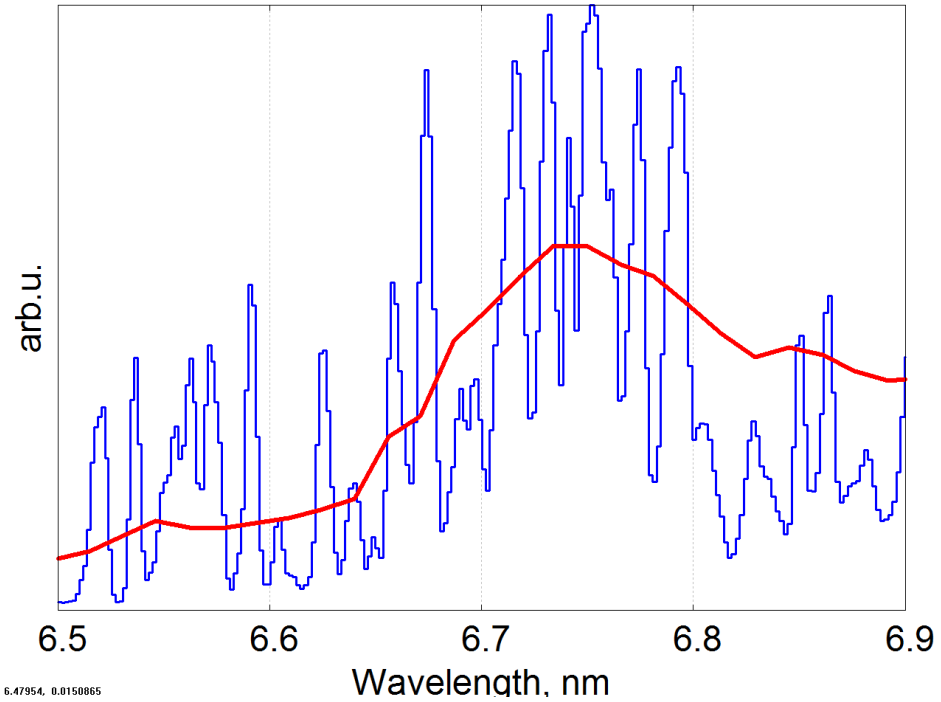
Detailed spectrum



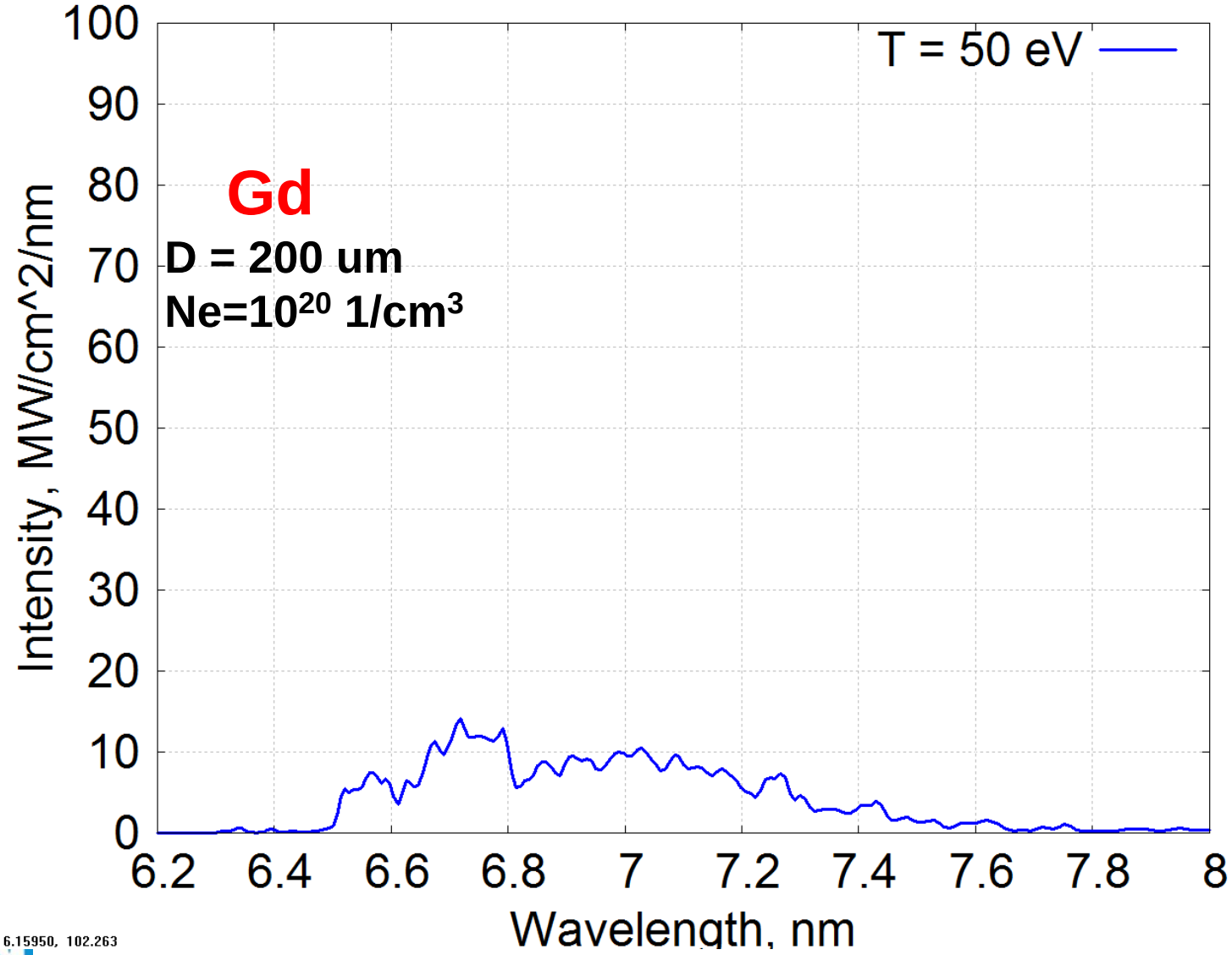
Influence of broadening

Sn vs Gd



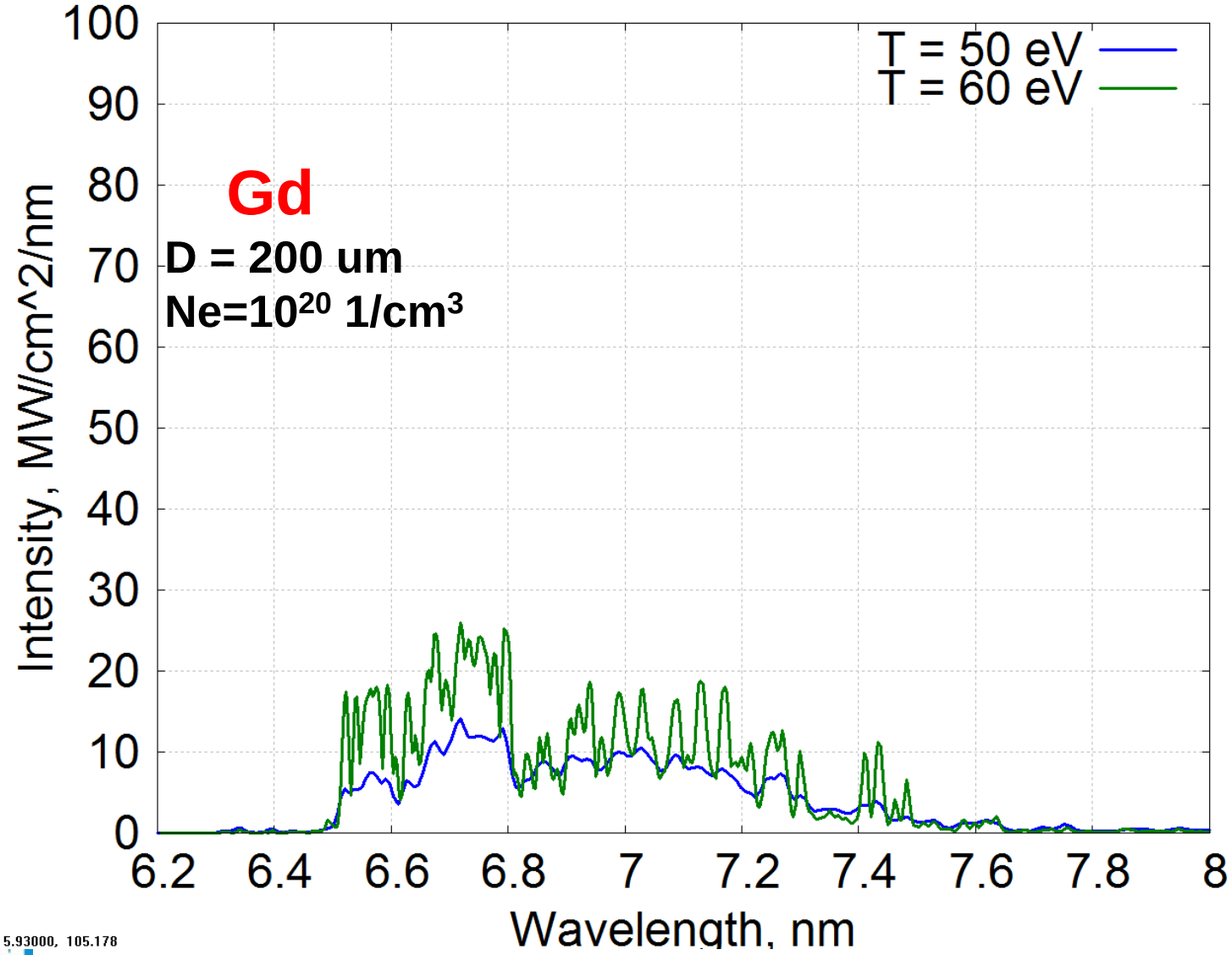


Temperature dependence



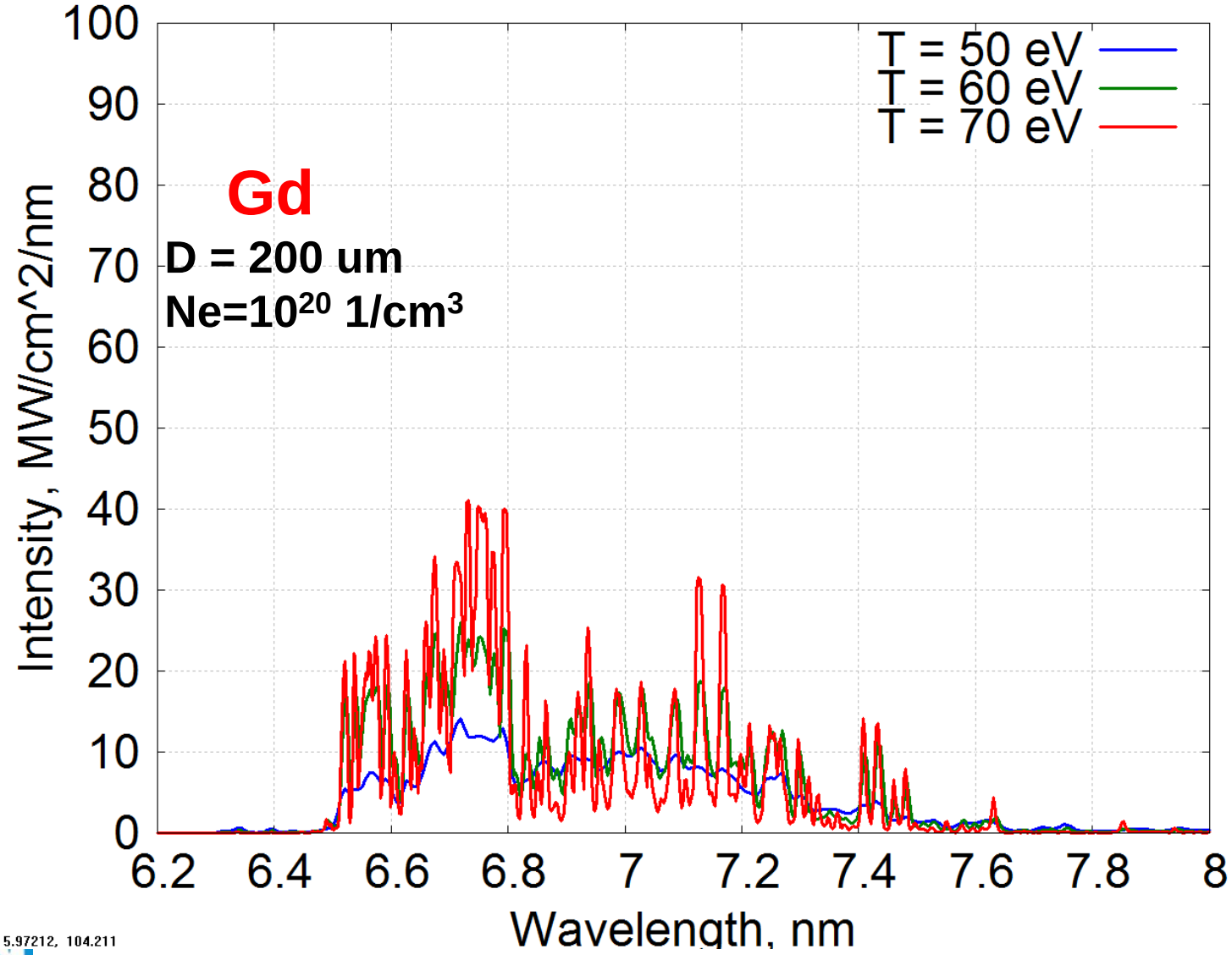
6.15950, 102.263

Temperature dependence



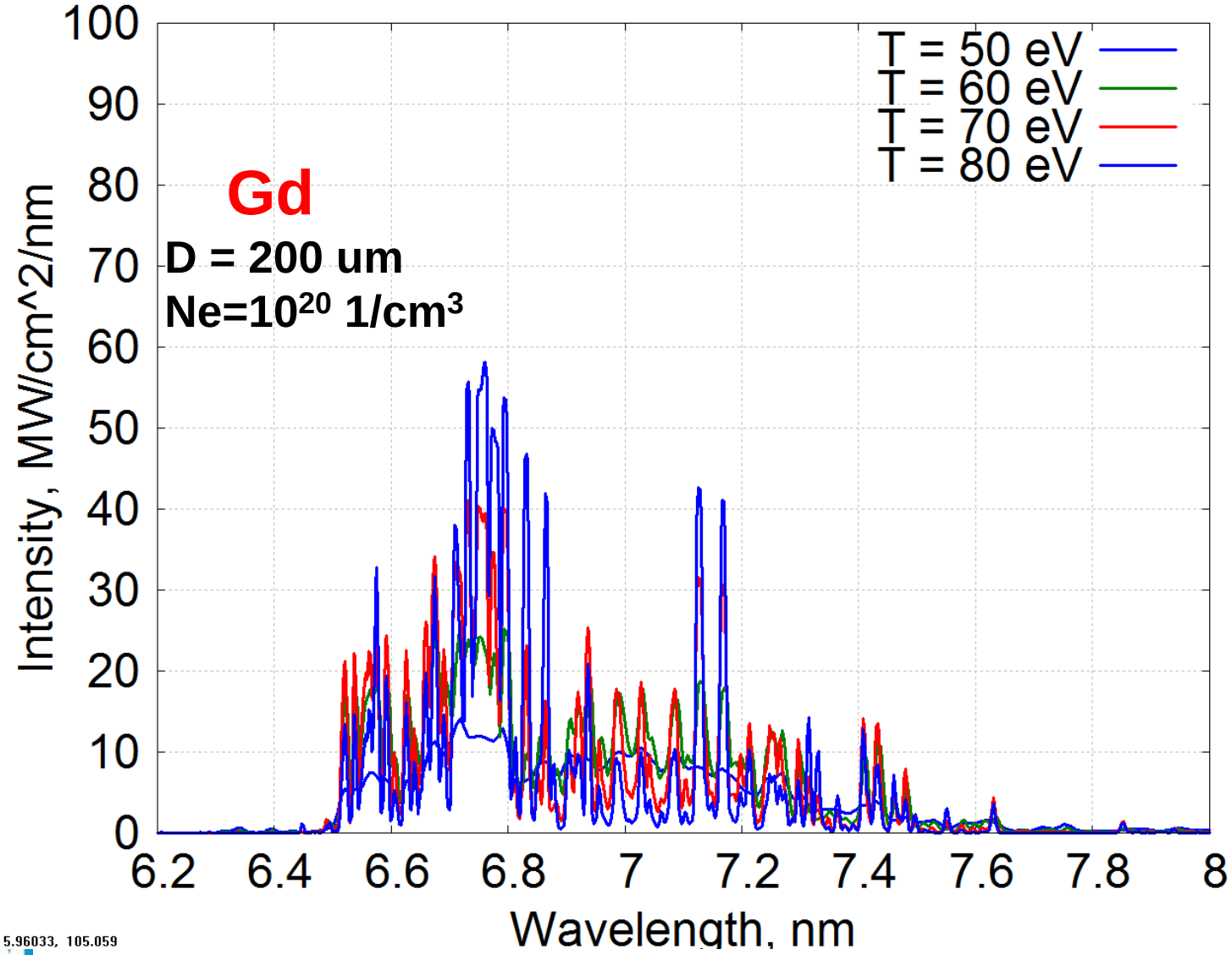
5.93000, 105.178

Temperature dependence



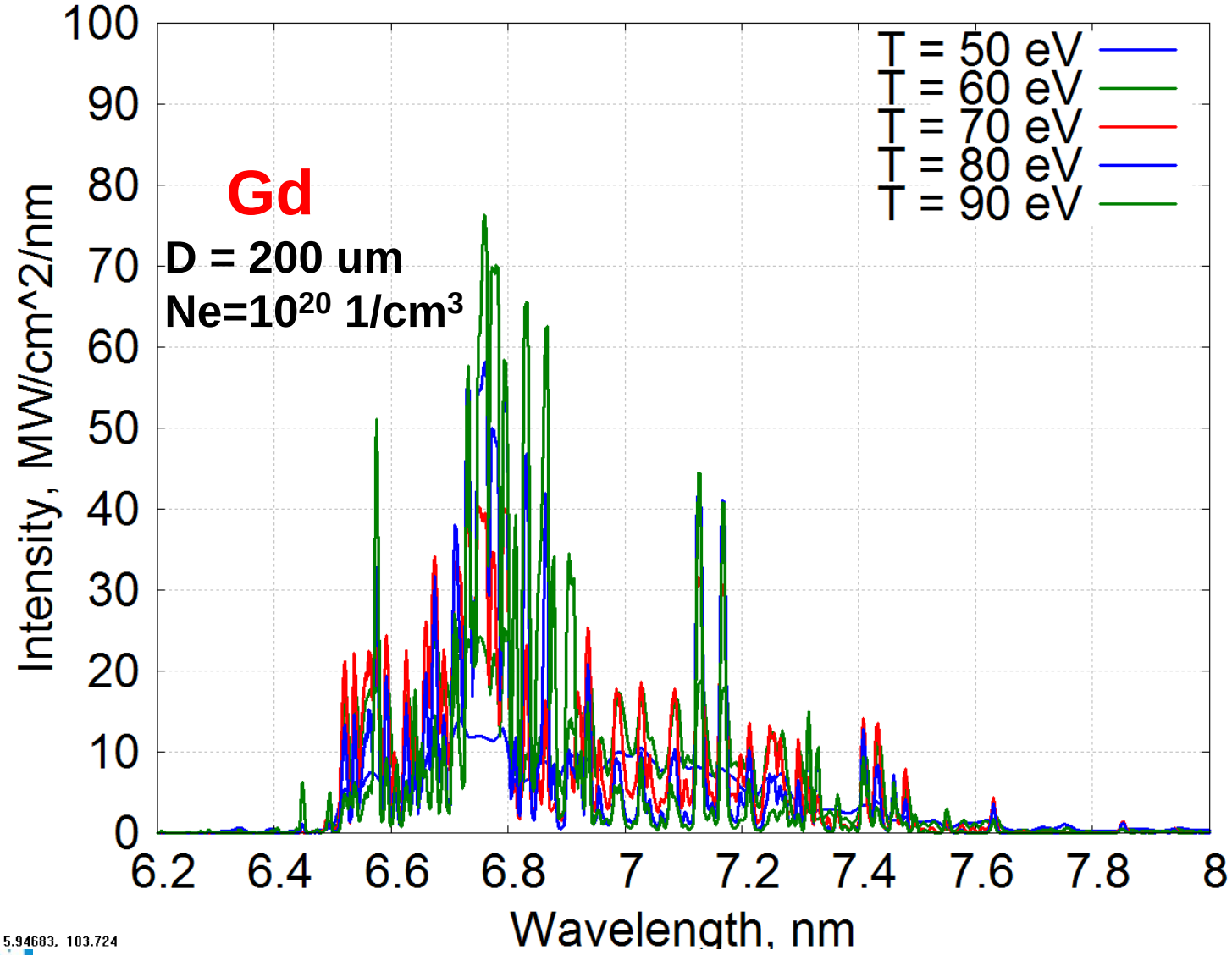
5.97212, 104.211

Temperature dependence



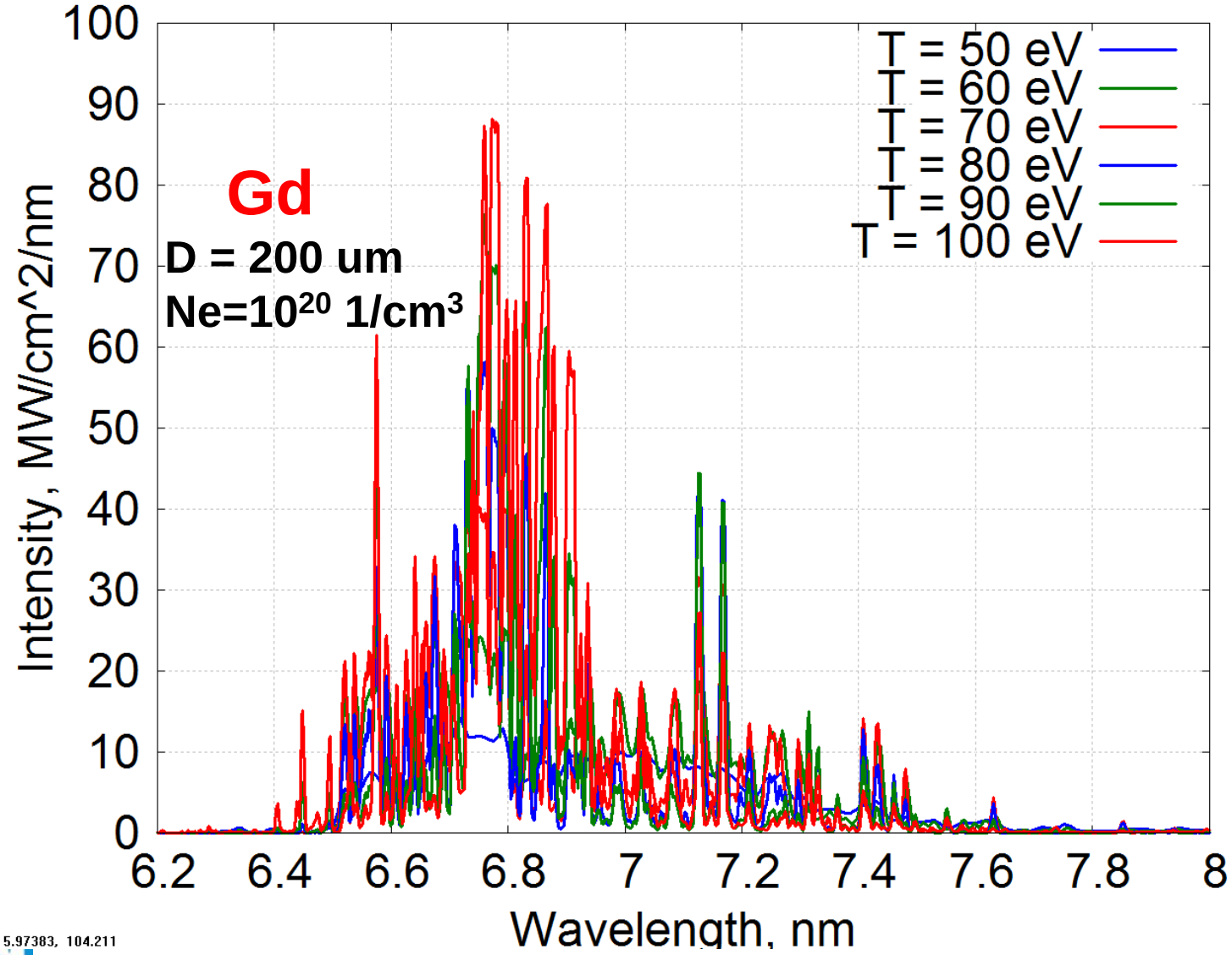
5.96033, 105.059

Temperature dependence



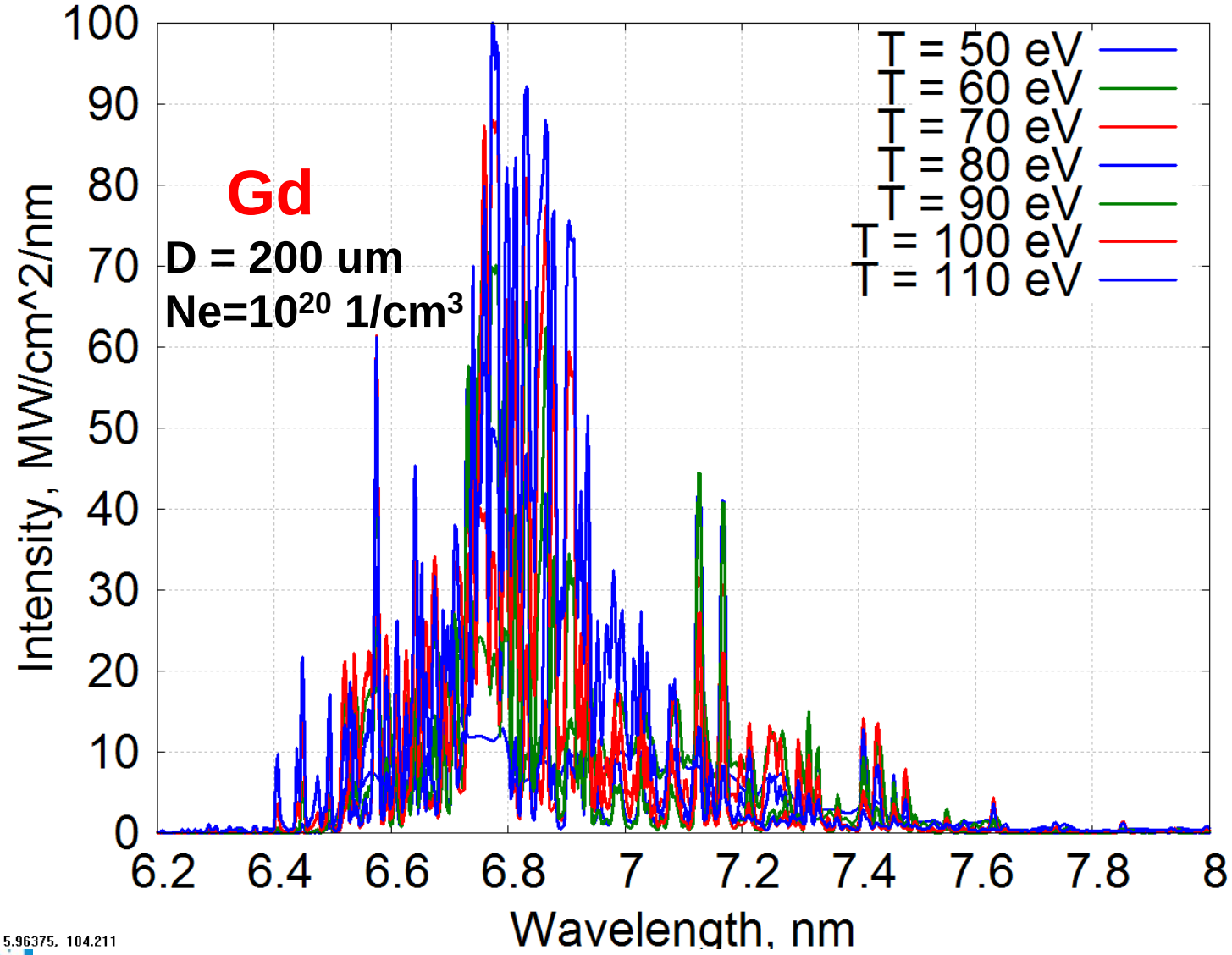
5.94683, 103.724

Temperature dependence



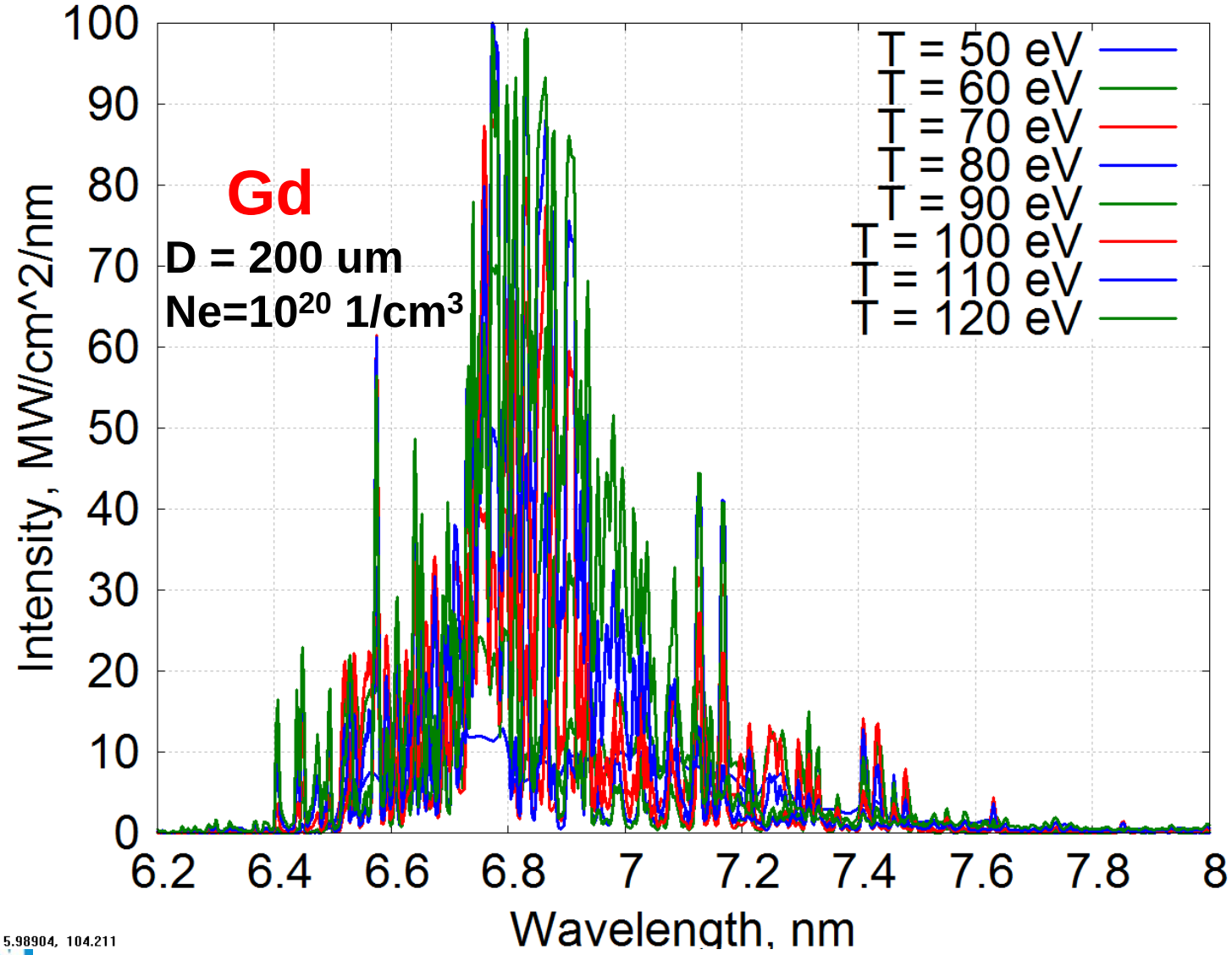
5.97383, 104.211

Temperature dependence



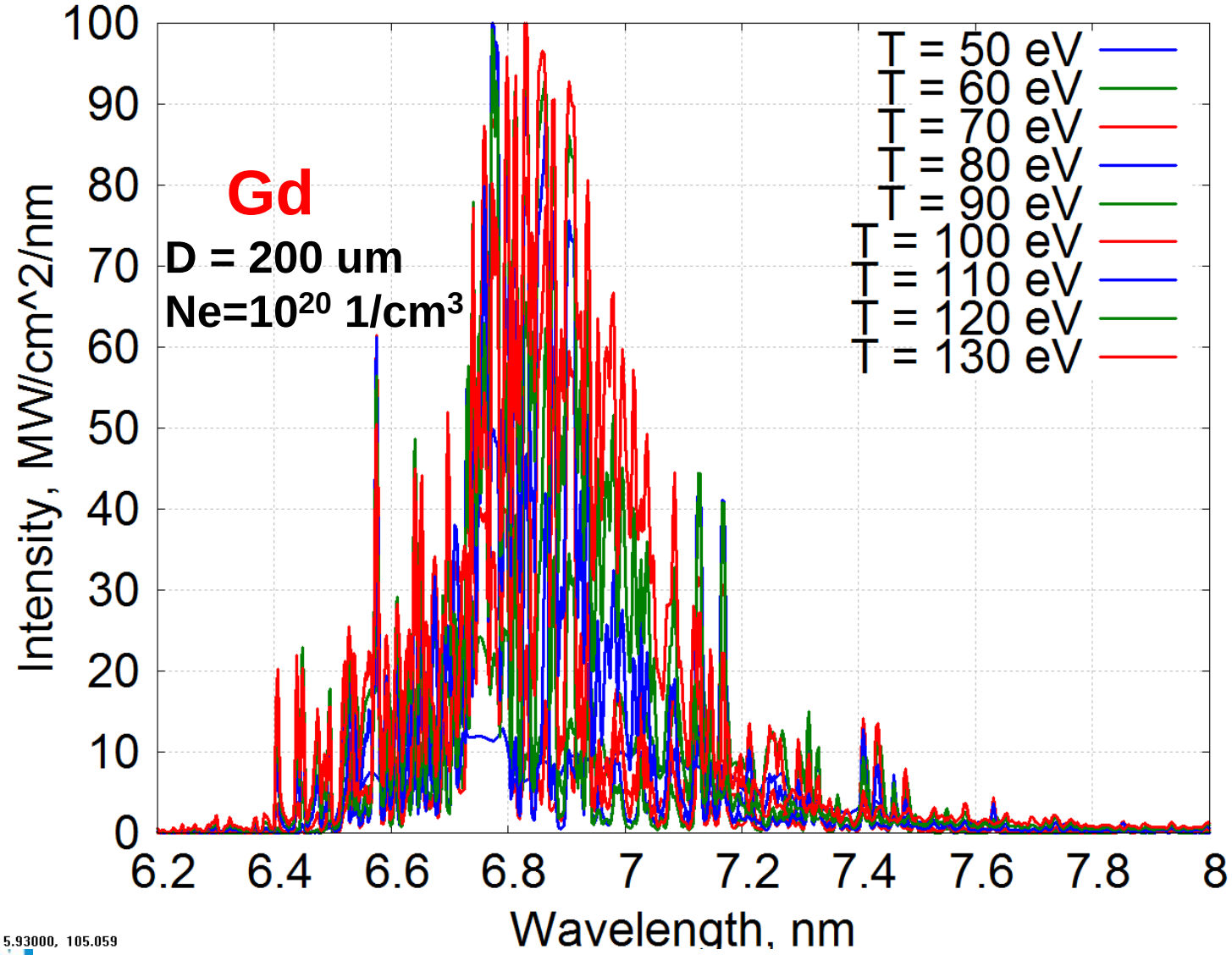
5.96375, 104.211

Temperature dependence



5.98904, 104.211

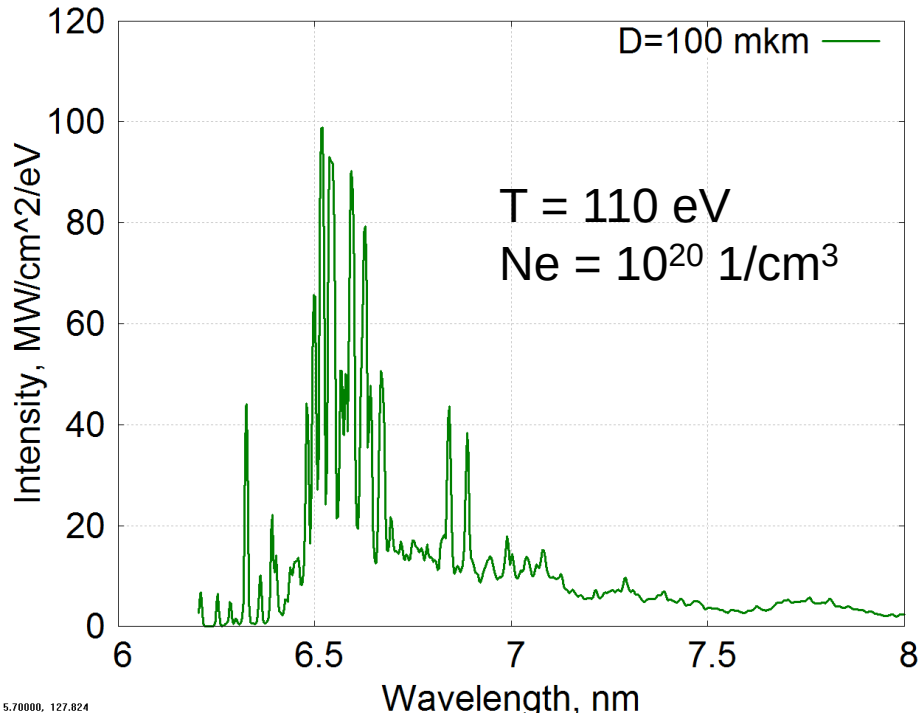
Temperature dependence



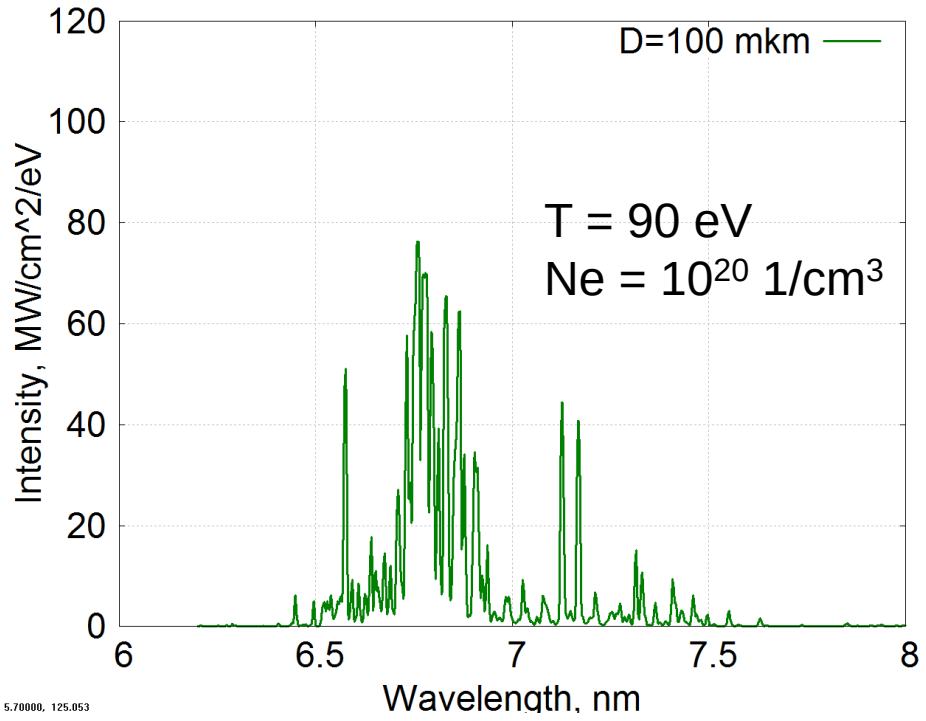
5.93000, 105.059

Dependence on plasma size

Tb

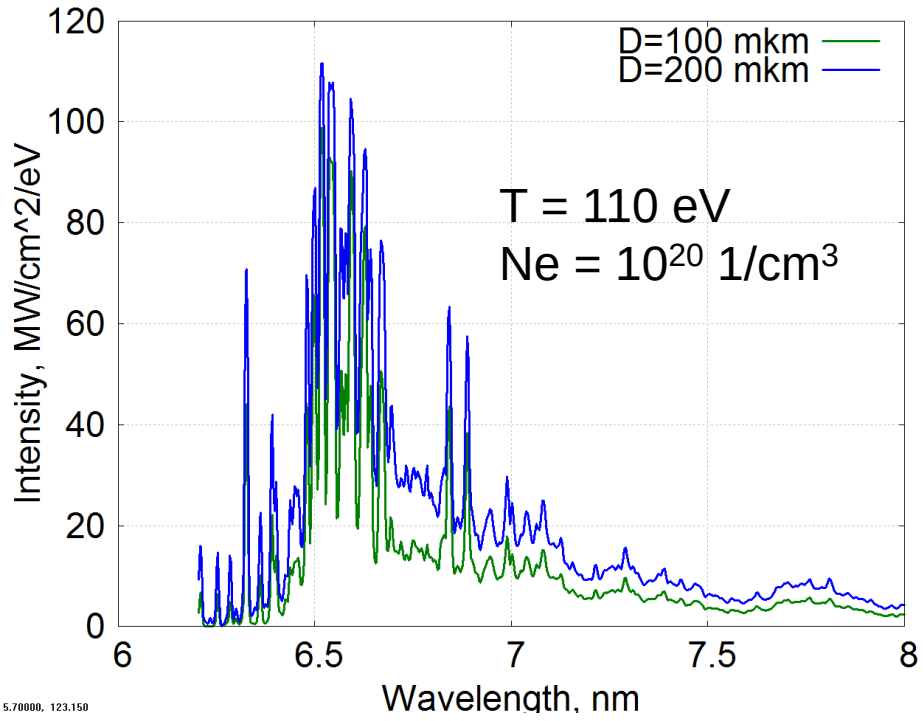


Gd

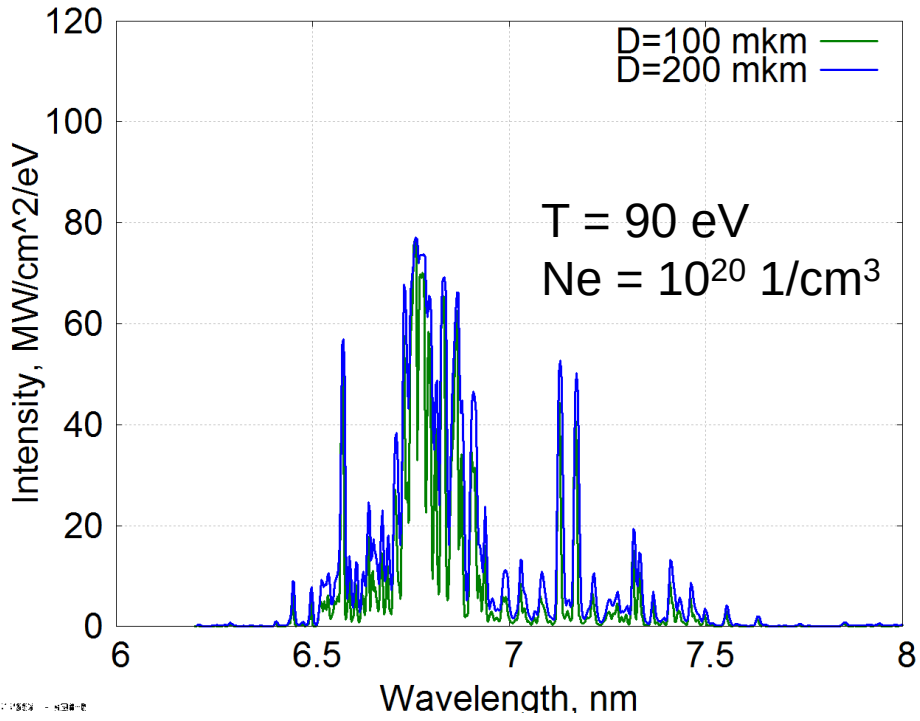


Dependence on plasma size

Tb

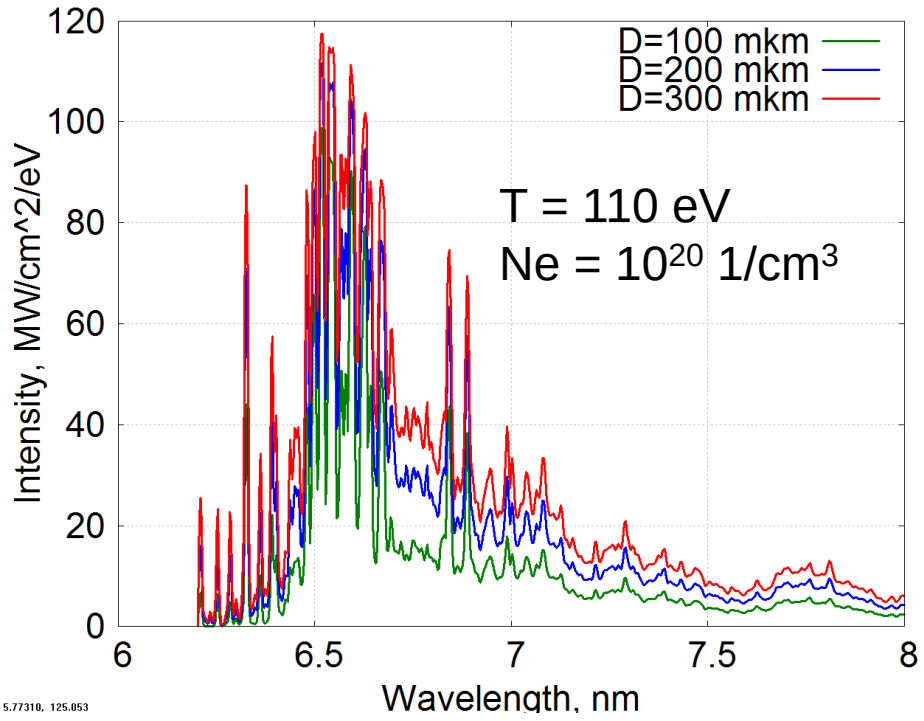


Gd

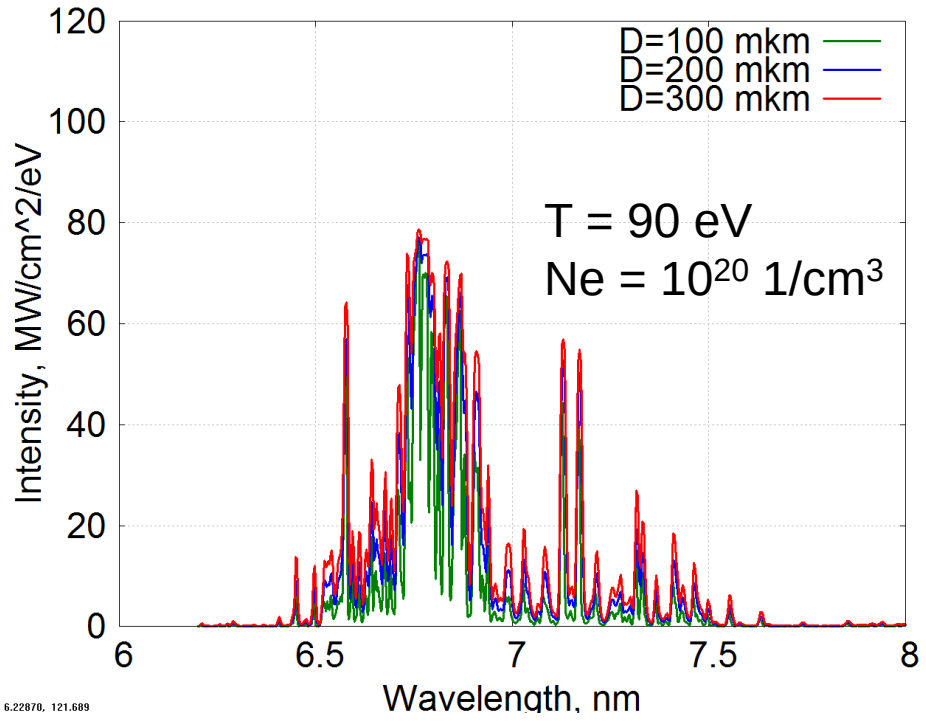


Dependence on plasma size

Tb



Gd



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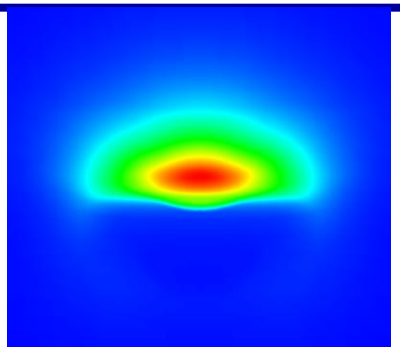
Ions	VIII - XIV	XVII - XXII
Temperature	~ 35 eV	~ 100 eV
Size	~ 200 um	~ 200 um
Optical thickness	~ 1	~ 1
Electron density	~ 10^{19} 1/cm^3	~ 10^{20} 1/cm^3
CE	~ 7%	~ 3%

More realistic modeling is based on RHD calculations with the code RZLINE

RZLINE code



2D Eulerian RMHD code

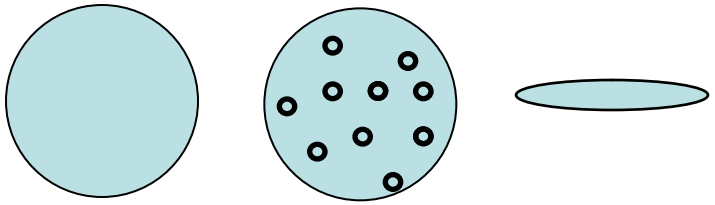
Laser tracing,
absorption and reflection of laser pulse,
energy fluxes to and from target,
electron and ion thermo-conductivity,
radiative transfer in ~100 spectral groups,
evaporation and condensation of target,
ionization and recombination of plasma.

Diffusion-like spectral radiation transport,
calculation of EUV source size,
detailed spectra,
anisotropy of EUV radiation,
fast ions.

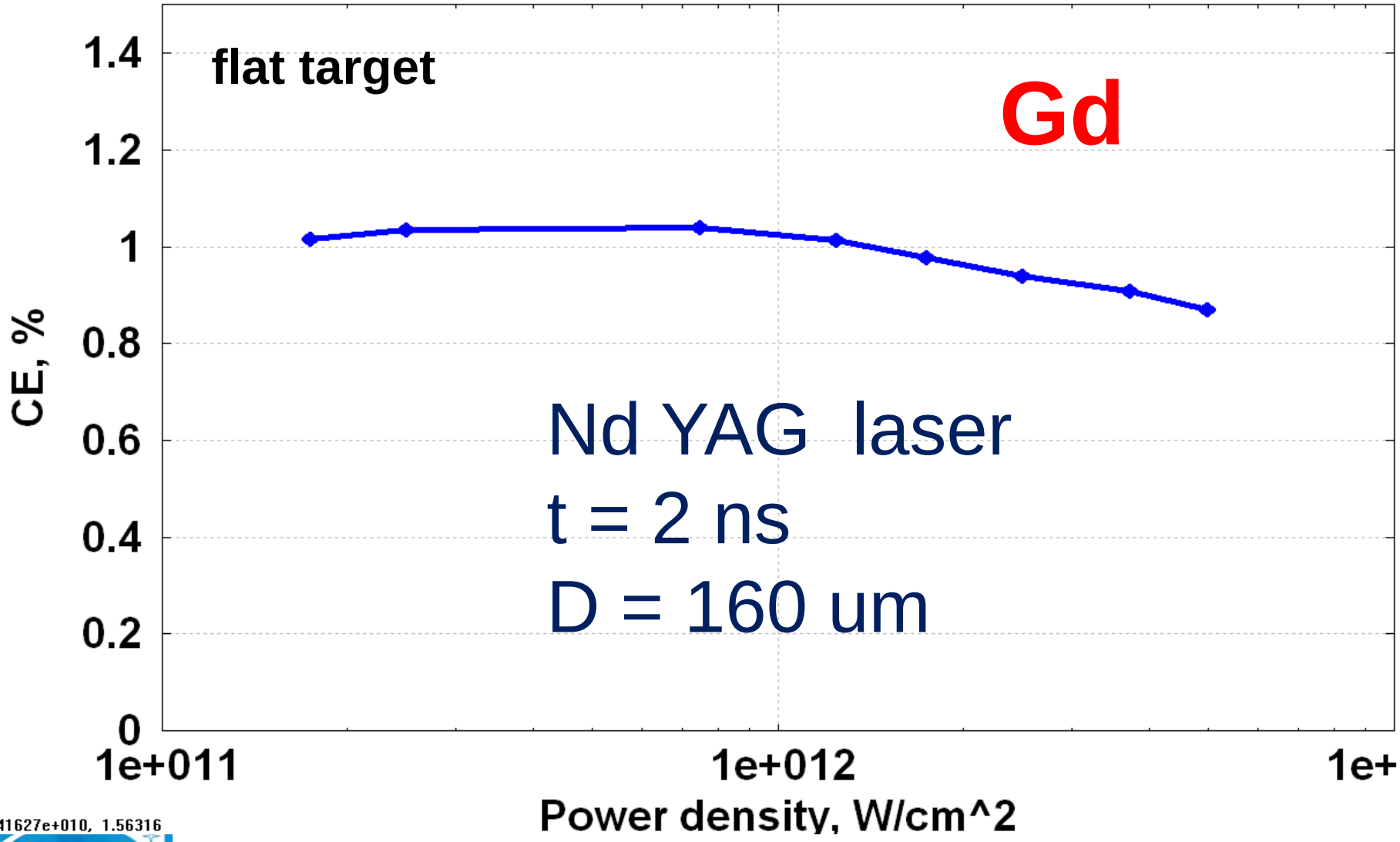
Nonhomogeneous grid ~ 10^5 r,z cells
Calculation time ~ 2 hours on PC

RZLINE works with two types of tables:
1.Transparent case table
2.Optically thick case table
(nontrasparent in band)

Temperature	1 – 500 eV
Electron density	10^{14} – 10^{23} 1/cm
Photon energy range	1 – 1000 eV

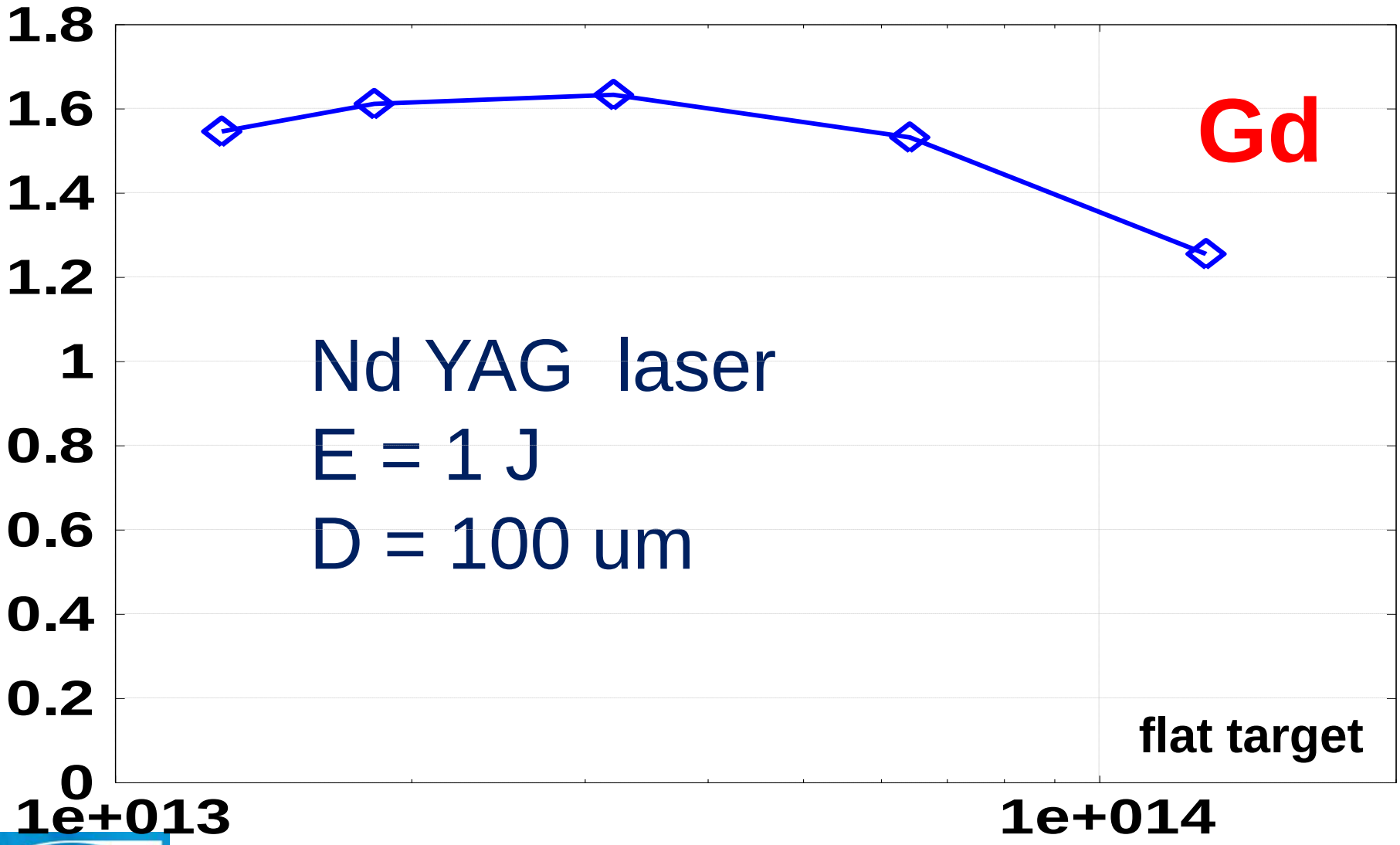


CE scaling

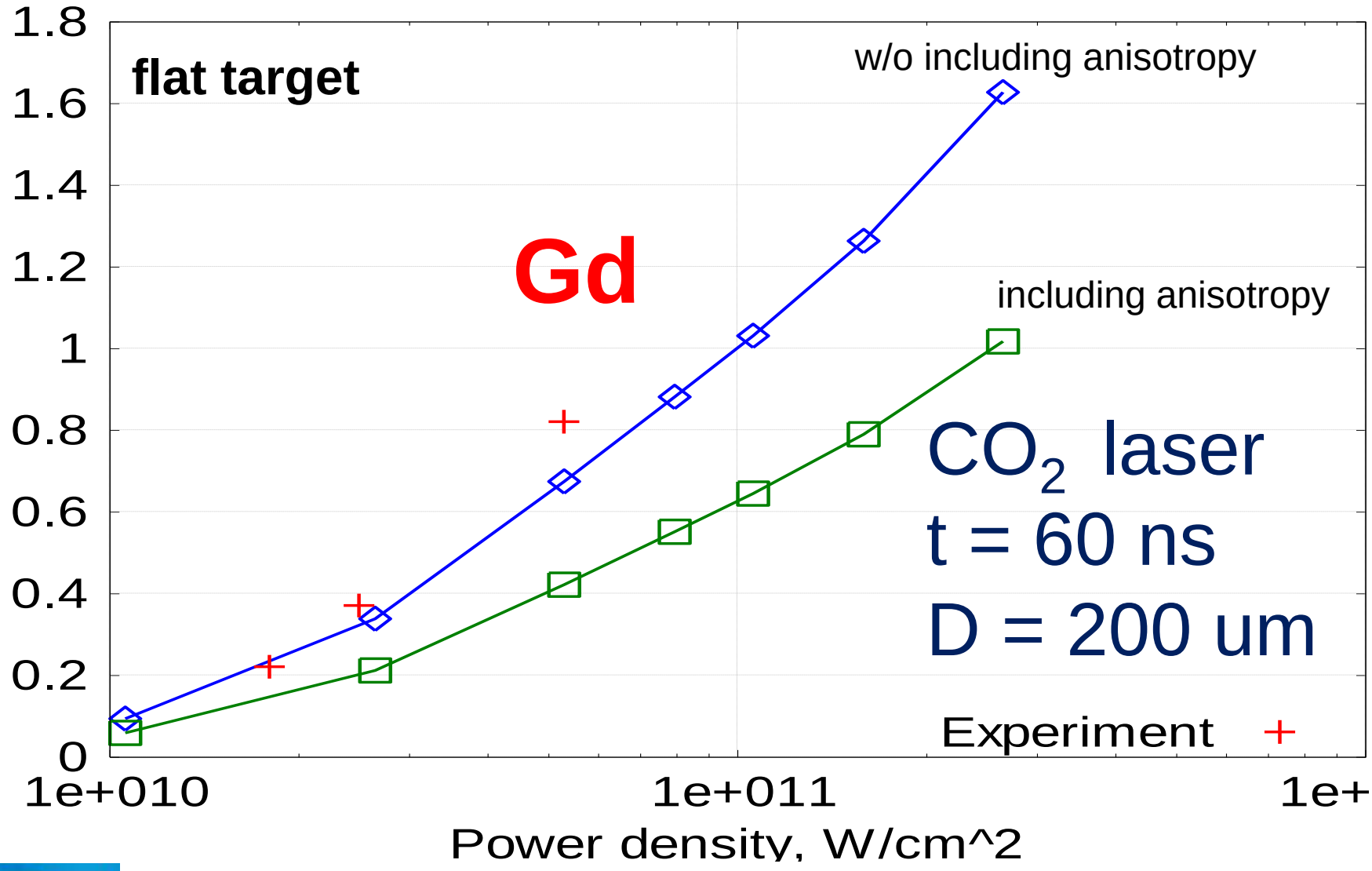


5.41627e+010, 1.56316

CE scaling

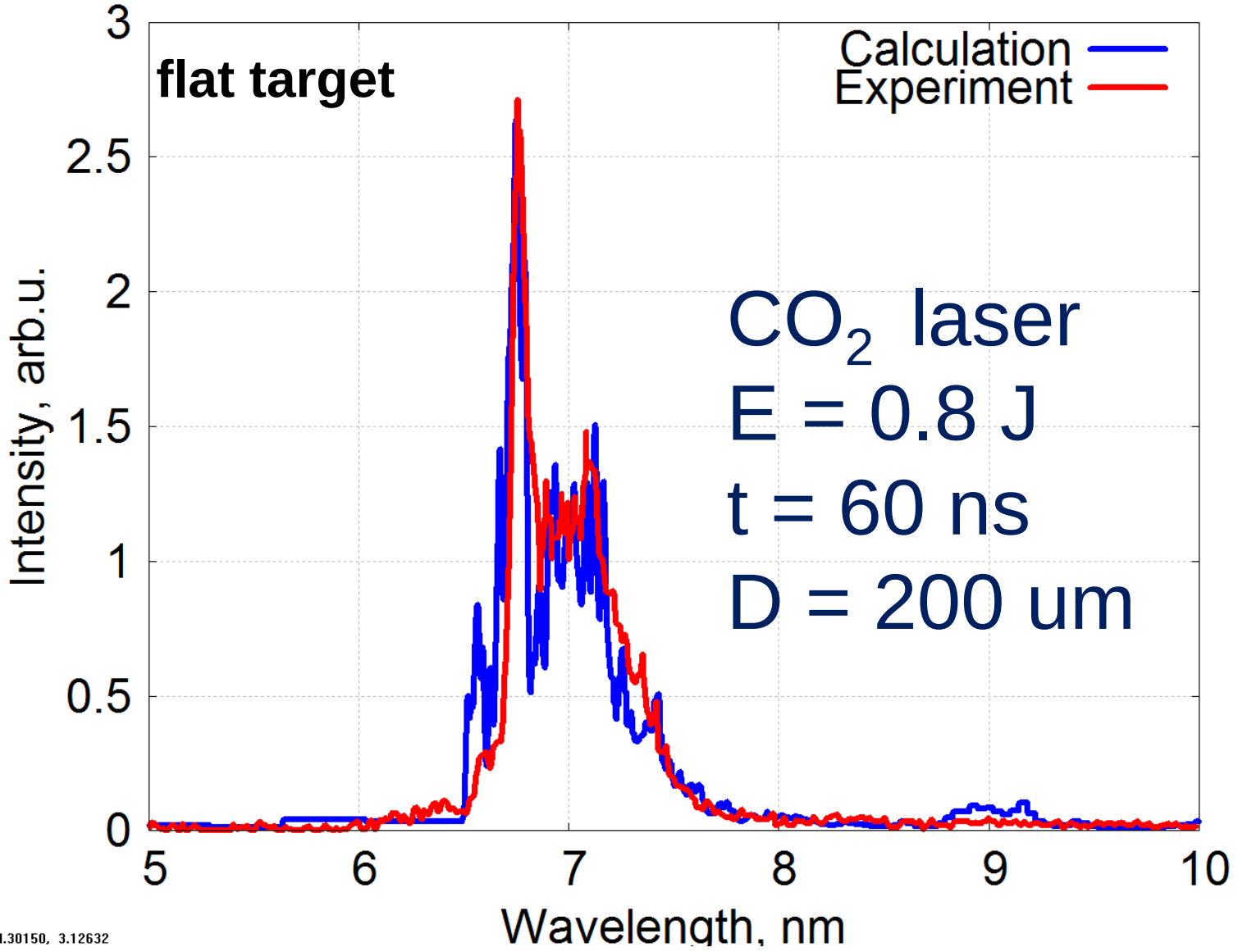

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1e+013
1e+014
Gd
Nd YAG laser
E = 1 J
D = 100 um
flat target

CE scaling


flat target
w/o including anisotropy
Gd
including anisotropy
CO_2 laser
t = 60 ns
D = 200 um
Experiment
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1e+010
1e+011
1e+01
Power density, W/cm^2

Comparison with experiment

Gd



4.30150, 3.12632

Conclusion

- Comparison of Gd & Sn plasma
  LPP source was fulfilled

- Optimal plasma for homogeneous Gd ball with size
  D ~ 200 um,T ~ 90 eV, Ne ~ 10^{20} 1/cm^3
  gives CE ~ 3 % in 0.6% band at 6.746 nm

- Modeling by using the code RZLINE gives
  for plate Gd target CE ~ 1 % for CO_2 laser